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APPARATUS AND METHOD FOR SENSING TEMPERATURE

by

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APPARATUS AND METHOD FOR SENSING TEMPERATURE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application Serial No. 60/390,511 filed June 21, 2002, having the same title and inventors as identified herein, which is incorporated by reference herein in its entirety.

FIELD OF THE INVENTION

[0002] The invention relates to temperature measurement in appliances. Specifically, the invention involves an apparatus and method for high precision temperature measurement.

BACKGROUND OF THE INVENTION

[0003] A conventional household oven allows a user to set a temperature for baking or cooking food. The oven heats an oven chamber to the desired temperature and attempts to maintain that temperature in the oven chamber for the duration of the cooking period. To heat the oven and maintain the oven temperature, the conventional household oven includes heating elements, a temperature sensor, and a controller. For the oven's basic operation, the heating elements are supplied with power to heat the oven chamber. The temperature sensor senses the temperature within the oven chamber and supplies a temperature measurement signal to the controller indicative of the temperature. Based on the temperature measurement signal, the controller compares the measured signal with the desired temperature/setpoint and sends a control signal to a heater drive. The heater drive is operatively connected to the heating elements, and is capable of varying the power to the heating elements to maintain the desired temperature setpoint within the oven chamber.

[0004] Typically temperature measurement using an RTD is done utilizing a regulated voltage supply along with amplifiers, and comparators that increase the gain of the voltage measured across the RTD. These measurements are usually performed using the low regulated power sources as the voltage supply. Regulation of the voltage as well as amplification of the circuit significantly increases the amount of materials required for the temperature measurement, the cost of the component, and the space required for the

measurement device. Moreover, to compensate for inaccuracy based on the circuits' calibration values, the offset determined at calibration is typically added to the measured temperature value during operation, which is less accurate than desired.

[0005] The present invention is directed to overcoming or at least reducing the effects of one or more of the problems set forth above.

SUMMARY OF THE INVENTION

[0006] The present invention relates to an apparatus for measuring the temperature in an appliance. The apparatus comprise a temperature transducer, the temperature transducer comprising a variable resistance that changes in response to the temperature. First and second resistors are coupled in series between a voltage supply and ground to form a first voltage divider. The junction of the first voltage divider is then coupled to an input of a microprocessor so as to provide the microprocessor with a signal indicative of the voltage across the first resistor. A third resistor coupled in series with the temperature transducer between the voltage supply and ground to form a second voltage divider. The junction of this voltage divider is coupled to another input of the microprocessor so as to provide a signal indicative of the voltage across the temperature transducer. The microprocessor then determines a temperature using the voltage across the temperature transducer and the second resistor to determine the resistance of the temperature transducer.

[0007] In another aspect, the apparatus may be constructed so that first and second resistors each comprise one or more individual resistors interconnected by one or more jumpers to provide suitable resistance values corresponding to the supply voltage. In still another aspect, the jumpers may also provides a signal to the microprocessor indicative of the supply voltage or resistance values selected. Alternatively, some other variable signal indicative of the supply voltage may be connected to the microprocessor.

[0008] In one aspect of the present invention, the microprocessor determines the temperature using a look-up table correlating the resistance of the temperature transducer to the temperature. In still another aspect, the temperature determined by the microprocessor is corrected by an offset value determined during a calibration routine and stored in memory of the microprocessor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Other objects and advantages of the invention will become apparent upon reading the following detailed description and upon reference to the drawings.

[0010] FIG. 1 is a block diagram of a typical household electric oven;

[0011] FIG. 2 is a circuit diagram illustrating an embodiment of the present invention.

[0012] FIG. 3 is a circuit diagram illustrating an alternative embodiment of the present invention.

[0013] While the invention is susceptible to various modifications and alternative forms, certain specific embodiments thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular forms described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION

[0014] Although the following description is in terms of a control system for an oven, it will be understood by those skilled in the art that it is applicable to all types of appliances including all types of ovens, refrigerators, freezers, washers, dryers and dishwashers.

[0015] Figure 1 is a block diagram of a household electric oven 10 according to one embodiment of the present invention. The oven comprises an oven chamber 42 having at least one heating element 41 and at least one temperature sensor 40. The oven 10 also has a user interface 18 that allows the user to control the operation of the oven 10. The user interface 18 is a typical interface on the front of a typical household oven. The interface 18 comprises a keypad with keys and/or dials that turn the oven on and off. Additionally, the keys and/or dials present on the user interface 18 instruct the oven to operate at particular temperature set point and operational mode. For example, the user selects the appropriate set point temperature for the oven chamber 42, such as 350 °F, and selects the operating mode, such as bake mode and self-cleaning mode with the user interface 18.

[0016] The user interface 18 generates signals indicating pressed keys and/or dial positions. These signals are transmitted from the user interface 18 to a control unit 20 through an analog-to-digital converter 22. The analog-to-digital converter 22 receives the

analog signals from the user interface 18 and transforms them into digital signals that are readable by the control unit 20. Although shown as separate elements, the analog-to-digital conversion can be done internally at the control unit 20 if it is the type of microcomputer or microprocessor equipped for such a purpose.

[0017] The control unit 20 receives and processes the signals from the user interface 18 through the analog-to-digital converter 22. The processing results in a series of control signals being sent from the control unit 20 to other elements of the oven to operate the oven at the desired oven temperature and in the desired oven mode. The control unit 20 sends control signals to a heater drive 24 that transmits power from a power source 26 to the heater elements 41. The control unit 20 may also send control signals to other elements of the oven, such as a fan, depending on the oven mode.

[0018] The control unit 20 also receives signals representing information stored in a memory 28. The memory 28 transmits its stored information signals over a data bus that is coupled to the control unit 20. In an alternative embodiment, the control unit 20 includes nonvolatile memory. The memory 28 stores information representing various heat settings in the oven's modes of operation. The control unit 20 requests the information stored in memory 28 based on the signal inputs received from the user interface 18. For example, if the user has selected the self-cleaning mode with the user interface 18, the control unit 20 obtains information from the memory 28 relating to the self-cleaning mode.

[0019] The control unit 20 also receives a signal representing an oven cavity temperature from the temperature sensor 40. The temperature sensor 40 is a standard resistive temperature device (RTD) sensor or any other temperature sensor known to those skilled in the art. The temperature signal is transmitted from the temperature sensor 40 to the control unit 20. In an alternative embodiment, the temperature signal from the temperature sensor 40 passes through an analog-to-digital converter (not shown). The analog-to-digital converter transforms the analog signals into digital signals for reading by the control unit 20 if the control unit 20 is only equipped to read digital signals.

[0020] The present invention relates to a circuit and algorithm for measuring the temperature of the oven chamber using the standard RTD temperature sensor.

[0021] Figure 2 illustrates one embodiment of the temperature measuring circuit of the present invention. The circuit includes an unregulated power source 11, a microprocessor 12, resistive temperature device (RTD) 17, resistors R1, R2, R3, diode 14, RC filter circuits 15 and 16, and ground connection 13.

[0022] The unregulated power source is a high voltage DC supply that can have nominal values of 24V, 32V, or 40V DC. Because the voltage supply is unregulated the actual voltage supply can have a variety of ranges.

[0023] As is known in the art, the resistance of the RTD 17 varies in proportion to the temperature being measured by the RTD 17. As shown in Figure 2, the resistor R3 and RTD 17 are series connected to form a voltage divider for the measuring the RTD 17 resistance. The voltage divider connection 21 measures the voltage across the RTD 17 and provides the value of the measurement to input 18 of microprocessor 12. The RC filter circuitry 15 filters any noise. Because the voltage supply is unregulated, to compensate for supply fluctuations, resistors R2 and R1 are connected in series to form a second voltage divider that represents the reference voltage. Voltage divider connection 22 has RC noise filter circuitry 16 and is connected to another input of the microprocessor. A diode 14 protects the microprocessor input 18 from over-voltage when the RTD 17 is disconnected.

[0024] Resistors R1 and R2 provide a signal below 5V DC for measuring the unregulated voltage supply. The values of resistors R1, R2, and R3 depend on the range of the unregulated supply for a given application, which in turn depends on the voltage requirements of any other devices connected within the circuitry. The microprocessor 12 as an analog-to-digital-converter (ADC) that converts the analog voltage readings into corresponding digital values.

[0025] It should be understood that any suitable values of supply voltage and component values can be used. However for illustrative purposes, the nominal values for a typical supply voltage have been used, as well as corresponding components. The microprocessor uses the voltage input 18 across the RTD 17 and the reference voltage input 19 across resistor R1 to compute the resistance of RTD 17. The microprocessor 12 then converts the resistance of the RTD 17 to a temperature value. Based on the measured voltage values across the RTD 17 and across the resistor R1 an equation is developed for

a value for the resistance of the RTD 17, which eliminates the unregulated voltage supply value. As is known in the art, the resistance of the RTD 17 can be represented by equation 1 below:

[0026]
$$R_{RTD} = \frac{R_1 \cdot R_2 \cdot V_{RTD}}{(R_1 + R_2) \cdot V_{REF} - R_1 \cdot V_{RTD}}$$

Equation 1

[0027] where: R_1 is the resistance of resistor R1; R_2 is the resistance of resistor R2; R_3 is the resistance of resistor R3; V_{RTD} is the measured voltage across RTD 17; and V_{REF} is the measured voltage across resistor R1.

[0028] Typical nominal values of the unregulated high voltage DC power source are 24V, 32V, or 40V DC. Because the voltage supply is unregulated the actual voltage supply can have a variety of ranges for these nominal values, as indicated in table 1 below. Moreover, based on the nominal voltage values of the power source, resistor values for the resistors R1, R2, R3 have been chosen for illustrative purposes to maximize the analog input values and improve the resolution. These resistive values are also indicated in Table 1 below.

Table 1

Nominal Voltage	Actual Voltage Range	R1	R2	R3
24V	16–28V	41.2 kΩ ± 1%	200 kΩ ± 1%	14.0 kΩ ± 1%
32V	22–38V	41.2 kΩ ± 1%	287 kΩ ± 1%	20.0 kΩ ± 1%
40V	28–48V	41.2 kΩ ± 1%	347 kΩ ± 1%	26.1 kΩ ± 1%

[0029] As shown in Table 1, based on these nominal voltage values 11, the resistance of R1 is a constant value of 41.2 kΩ. Because the typical nominal voltage can vary based on the appliance manufacturer's standards, in one embodiment of this invention, the circuit design includes three resistors for R2 having the computed resistive values for each nominal voltage value, and three resistors for R3 having the computed resistive values for each nominal value. In this embodiment, a jumper is installed on the printed circuit board of the device and is used to indicate the manufacturer's nominal voltage supply. The manufacturer places the jumper across the correct pins of the printed circuit board to indicate the corresponding nominal voltage. Also in this embodiment, placement of the jumper also sends an input to the microprocessor 12, triggering the corresponding

resistors R1, R2, R3 value data stored within the memory of the microprocessor 12. In a alternative embodiment, rather than having a hardwired input signal sent to the microprocessor 12, based on the jumper position, the microprocessor 12 has a dial with multiple positions, indicative of the nominal voltage values. The dial is adjustable to allow the manufacture to select the desired nominal voltage value. Because the costs of the additional resistors and jumper components is minuscule, this design allows for lower manufacturing cost, by enabling the manufacture to produce one device that is end use configurable based on the end users requirements.

[0030] In one embodiment a data look-up table of degree Fahrenheit values an corresponding resistor values, shown in Table 2, is stored in the microprocessor's 1 read-only-memory (ROM). In this embodiment, based on Equation. 1, the microprocessor 12 calculates the resistance of the RTD, and then using the stored ROM values indicated in Table 2, and interpolation, the microprocessor 12 calculates the temperature measured by the RTD 17.

Table 2

°F	Ω	°F	Ω	°F	Ω	°F	Ω
0	932.060	250	1452.628	500	1949.962	750	2424.076
10	953.340	260	1472.967	510	1969.372	760	2442.557
20	974.572	270	1493.269	520	1988.746	770	2461.002
30	995.766	280	1513.534	530	2008.082	780	2479.409
40	1016.922	290	1533.762	540	2027.381	790	2497.779
50	1038.042	300	1553.952	550	2046.642	800	2516.112
60	1050.124	310	1574.106	560	2065.867	810	2534.408
70	1080.169	320	1594.222	570	2085.054	820	2552.666
80	1101.177	330	1614.301	580	2104.205	830	2570.888
90	1122.148	340	1634.348	590	2123.318	840	2589.072
100	1143.081	350	1654.343	600	2142.392	850	2607.219
110	1163.978	360	1674.316	610	2161.433	860	2625.330
120	1184.837	370	1694.246	620	2180.435	870	2643.402
130	1205.659	380	1714.140	630	2199.399	880	2661.438
140	1226.445	390	1733.996	640	2218.326	890	2679.437
150	1247.192	400	1753.815	650	2237.217	900	2697.398
160	1267.903	410	1773.597	660	2256.070	910	2715.322
170	1288.577	420	1793.341	670	2274.886	920	2733.210
180	1309.213	430	1813.049	680	2293.665	930	2751.059
190	1329.812	440	1832.720	690	2312.406	940	2768.872
200	1350.374	450	1852.353	700	2331.111	950	2786.648
210	1370.899	460	1871.949	710	2349.778	960	2804.386
220	1391.387	470	1891.508	720	2368.408	970	2822.088
230	1411.838	480	1911.030	730	2387.001	980	2839.752
240	1432.251	490	1930.514	740	2405.557	990	2857.379

[0031] It is known to those skilled in the art that deviations in the circuit's components value compromise the accuracy of the RTD 17 temperature measurement and creates an

offset in measured value. To compensate for this offset, calibration of the circuit is required. Calibration is performed by replacing the RTD 17 with a known resistance, representative of an ideal temperature. The microprocessor 12 is put in calibration mode and prompts the programmer to input the known resistance value. Based on the known resistance value, the microprocessor 12 chooses a temperature value corresponding to the known resistance, referred to as an ideal temperature. The microprocessor 12 then using Eq. 1 calculates the actual measured resistance and the corresponding temperature value. The microprocessor 12 then subtracts the measured temperature from the ideal temperature; the resulting value is the circuit's offset. This offset is stored in the ROM of the microprocessor 12.

[0032] In one embodiment of this invention, during normal operation of the circuit, the offset value is added to the measured temperature value, to provide a more accurate representation of the actual measured temperature. In a further aspect of this embodiment, for increased accuracy, the offset value is multiplied by the resistance of the ideal temperature used for calibration purposes and this value is then divided by the actual measured temperature, resulting in a percentage offset value. In this embodiment, rather than add the entire offset amount to the measured temperature value, the percentage offset value is added to the measured temperature value, providing a more accurate representation of the actual measured temperature.

[0033] In a further embodiment of this invention, efficiency in calculating the measured temperature and simplification of the software is achieved by manipulating Equation 1 to include a constant K and developing a value termed 'internal value', which can be used to determine the measured temperature. Equation 1 can be manipulated to include the constant K resulting in Equation 2:

[0034]
$$\frac{(R_1 \cdot R_3)}{K \cdot R_{RTD}} = \frac{(R_1 + R_2) \cdot V_{REF} - R_1 \cdot V_{RTD}}{K \cdot V_{RTD}}$$

Equation 2

[0035] Equation 2 above represents the 'internal value' as well as Equation 7 below. The 'internal value' is inversely proportional to sensor resistance. In Equation 2, the voltage units cancel each other out. This allows the raw 10-bit analog input values to be used directly for V_{REF} and V_{RTD} without actually converting them to volts.

[0036] $$InternalValue = \frac{K_R \cdot V_{REF} - K_S \cdot V_{RTD}}{V_{RTD}} = \frac{R_1 \cdot R_3}{K \cdot R_{RTD}}$$

Equation 7

[0037] where: $K_R=(R_1+R_2)/K$; $K_S=R_1/K$; and $K=(R_1 \bullet R_3)/(InternalValue \bullet R_{RTD})$.

[0038] Equation 3 represents the value of the constant K. Because the value of K depends upon the values of R_1 and R_3, a value for K has to be determined for each of the unregulated nominal voltage supply values. Because the internal value is inversely proportional to the resistance of the RTD, and the resistance of the RTD increases as the temperature increases, the value of 12288 decimal or 3000 hex is selected as the maximum to indicate a temperature of 0 deg F, which has an ideal resistance value of 963.63 Ω, based on Table 2. In binary form, this 3000 hex maximum value is much lower than the maximum 16-bit value. Based on this, the maximum 'internal value' can be determined using Equation 3.

[0039] $$K = \frac{(R_1 \cdot R_3)}{InternalValue \cdot R_{RTD}}$$

Equation 3

[0040] Using these values, a value for K at each nominal voltage value can be determined as shown in Table 3 below. Also values for K_R and K_S can be computed as shown above. Therefore using these equations, values for K, K_R and K_S are computed and shown in Table 3 below.

Table 3

Nominal Voltage Supply	K	K_R	K_S
24V	50.36119	4789	818
32V	74.94456	4562	573
40V	93.88765	4422	439

[0041] The values of K, K_R and K_S shown in Table 3 are programmed into the microprocessor's 12 ROM. Based on the circuit's nominal voltage supply 11, determinable by a jumper connection and/or a dial setting on the microprocessor 12, the microprocessor selects the correct values to calculate the RTD 17 temperature measurement.

[0042] Based on the 'internal values' for various resistance and equivalent temperature values, a look-up table, illustrated in Table 4, is generated and stored in the microprocessor's 12 ROM. Based on a 256 value decimal decrement being subtracted initially from the maximum 'internal value' 12288, and each iteration thereafter, Table 4 has 34 reference points termed i, that range consecutively from 0 to 33. Each i value corresponds to a specific 'internal value' and corresponding temperature value in degrees Fahrenheit, as illustrated in Table 4.

Table 4

ROM Table for Degrees Fahrenheit Conversion

i	Internal Value		Table
0	3840	0F00 hex	1056
1	4096	1000 hex	955
2	4352	1100 hex	864
3	4608	1200 hex	783
4	4864	1300 hex	713
5	5120	1400 hex	650
6	5376	1500 hex	594
7	5632	1600 hex	543
8	5888	1700 hex	498
9	6144	1800 hex	456
10	6400	1900 hex	418
11	6656	1A00 hex	383
12	6912	1B00 hex	351
13	7168	1C00 hex	322
14	7424	1D00 hex	294
15	7680	1E00 hex	269
16	7936	1F00 hex	245
17	8192	2000 hex	223
18	8448	2100 hex	203
19	8704	2200 hex	183
20	8960	2300 hex	165
21	9216	2400 hex	148
22	9472	2500 hex	132
23	9728	2600 hex	116
24	9984	2700 hex	102
25	10240	2800 hex	88
26	10496	2900 hex	75
27	10752	2A00 hex	63
28	11008	2B00 hex	51
29	11264	2C00 hex	40
30	11520	2D00 hex	29
31	11776	2E00 hex	19

32	12032	2F00 hex	9
33	12288	3000 hex	0

[0043] An example of operation of the circuit is illustrated below, using the following values and referring to Figure 2. As illustrated by this example, the RTD 17 actual temperature is 350 °F.

[0044] Nominal Voltage Supply = 32 V

[0045] Actual Voltage Supply = 31 V

[0046] R_{RTD} = 1654.3

[0047] V_{REF} = 3.852 V = 788 after ADC

[0048] V_{RTF} = 2.379 V = 487 after ADC

[0049] Using these values as well as the values for K_R and K_S shown in Table 3, the internal value is calculated using Equation 7 to be 6809 (rounded).

[0050] As shown in Table 4, the smallest 'internal value' is 3840, which represents the largest temperature value of 1056, indicated as $Table_1$. Hence calculation of i is computed as follows: i = (InternalValue=8340)/256 (truncated) = 11. Once i has been calculated, the Degree Measurement (Deg.Meas.) is computed using the equation below, and referring back to Table 4. The microprocessor 12 interpolates to determine the Deg. Meas. value.

[0051] $$Deg.Meas. = \frac{Table_i - (Table_i - Table_{i+1}) \cdot InternalValue - 3840 - 256 \cdot i}{256}$$

[0052] Using the above equation and the example above, the Deg.Meas. value is 364 °F, whereas the actual temperature of the RTD 17 is 350 °F. As previously mentioned, a further embodiment of this invention includes adjustment of the temperature for the offset determined by the initial calibration. In this embodiment of the invention, for increased accuracy, the calibration adjustment to the temperature measurement is proportional to the actual resistance measured. To further increase the accuracy, the calibration is performed at a resistance that corresponds to a relatively high temperature, so that the adjustment can be proportionally reduced for lower temperatures. The internal value is inversely proportional to the resistance, therefore the internal value is in the denominator of the calibration adjustment equation.

[0053] An example of the calibration, to determine to offset is illustrated below. In this example, the RTD 17 is replaced with a resistance that has a value of 2199.4 Ω that represents an ideal temperature of 630 °F. During calibration the following is an example of the actual supply voltage and measured RTD 17 and reference voltages used:

[0054] Nominal Voltage Supply = 32 V

[0055] Actual Voltage Supply = 34V

[0056] R_{RTD} = 2199.4

[0057] V_{REF} = 4.224 V = 864 after ADC

[0058] V_{RTF} = 3.384 V = 692 after ADC

[0059]. The internal value, i, and Deg. Meas. are calculated using the same method used for calculating the example actual operational measurement. Thus the following values are computed by the microprocessor 12:

[0060] Calibrated InternalValue = 5123

[0061] Calibrated i = 4

[0062] Calibrated Deg.Meas = 649 °F

[0063] As indicated by the calibration, the offset of the circuit is -19 °F, determined by subtracting the Cal. Deg. Meas. from the actual value (equivalent temperature value based on the resistance of the calibrating resistor).

[0064] Using the offset value of -19 °F, the Compensated Deg. Meas. is more accurately determined using the Deg. Meas. of 364 °F computed earlier and the offset. Using the offset calculation, which compensates for the error determined at calibration, the Compensated Deg. Meas. of 349 °F is much closer to the Actual Deg. Meas. of 350 °F.

[0065] Although the embodiments have discussed the use of only one RTD 17, in a further embodiment of the present invention, multiple RTDs 17, 17' are used along with multiple series resistors R3, R3', as illustrated in Figure 3

[0066] The foregoing description of preferred and other embodiments is not intended to limit or restrict the scope or applicability of the inventive concepts conceived of by the Applicants or defined in the appended claims. In exchange for disclosing the inventive concepts contained herein, the Applicants desire all patent rights afforded by the appended claims. It is intended that the inventive concepts defined by the appended

claims include all modifications and alterations to the full extent that such modifications or alterations come within the scope of the appended claims or the equivalents thereof.